ECONOMIC EVALUATION OF CSIRO INDUSTRIAL RESEARCH

Overview of four case studies

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Foreword

This report summarises four case-study evaluations of research by CSIRO in industrial and communication technologies. These evaluations, which were sponsored by CSIRO, had as one of their goals the investigation of how CSIRO could best allocate their limited resources across competing R&D applications.

The four case studies on which this report is based are separately described in BIE Research Papers. Research Paper No. 4 covers the Dunlena Agreement, No. 5 the CDT Synchro Pulse Welder, No. 6 Earth Station Antennas, and No. 9 National Measurement Standards.

The report would not have been possible without the co-operation of CSIRO divisions and responsible for industry research and its use. Particular thanks go to the CSIRO officers in the relevant Divisions and the Institute planners Garrett Upstill and Ian Elsum. In addition the assistance of firms who provided information on the industrial aspects of the various innovations is gratefully acknowledged.

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Director

Abbreviations

BC	benefit-cost
BIE	Bureau of Industry Economics
BIPM	Bureau International des Poids et Mesures (International Bureau of Weights and Measures)
CB	cost-benefit
CBA	Cost-benefit analysis
CDT	Controlled drop transfer (describes the WIA pulse welding unit)
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
DAP	Division of Applied Physics: the CSIRO Division containing the National Measurement Laboratory: part of the CSIRO Institute of Industrial Technologies
DCF	Discounted cash flow
DCP	Division of Chemicals and Polymers in the CSIRO Institute of Industrial Technologies
DITAC	Department of Industry, Technology and Commerce
DMT	Division of Manufacturing Technology - a division of the CSIRO Institute of Industrial Technologies
DR	Division of Radiophysics in the CSIRO Institute of Information Science and Engineering
DTI	Department of Trade and Industry (UK)
EC	European Community
IISE	Institute of Information Science and Engineering - a CSIRO institute
IIT	Institute of Industrial Technologies - a CSIRO institute
INMS	Institute for National Measurement Standards (Canada)
IRI	Industrial Research Institute
NATA	National Association of Testing Authorities
NML	National Measurement Laboratory
NMS	National Measurement System
NPV	Net present value
NSC	National Standards Commission
PA	Priorities Assessment (the CSIRO framework for R&D priority setting)
PRT	Platinum Resistance Thermometer
R&D	Research and development
SAA	Standards Australia; formerly the Standards Association of Australia
S&T	Science and technology
UK	United Kingdom
US	United States of America
WIA	Welding Industries of Australia P/L

The report at a glance

The report summarises the findings of four case-study evaluations of CSIRO research into industrial and communication technologies. The case studies were: the development and commercialisation of the *CDT pulse-welding unit* by CSIRO and Welding Industries Australia; the *Dunlena agreement*, a commercial agreement with Du Pont, which has facilitated CSIRO's research into crop-protection chemicals and which seeks to maximise Australia's benefits from CSIRO discoveries; the advanced design of *earth-station antennas*, as used by OTC for satellite communication; and the provision and maintenance of Australia's *national measurement standards* by the National Measurement Laboratory (NML).

The purpose of the evaluations was to assist CSIRO researchers determine the relative worth of their research in various fields, and thereby contribute to future decisions on the allocation of resources. A range of criteria were agreed to be relevant to R&D evaluation (see BIE,1990). These criteria ranged from cost-benefit analysis, an all-encompassing formal criterion, through individual industry-policy objectives such as international competitiveness, demonstration effects, human capital formation, national technological capability, to inter-industry and community "spillover" effects.

Of the criteria used, the benefit-cost ratio was found to be the best overall determinant of benefit to Australia. Estimating a benefit-cost ratio proved impossible in only one of the evaluations, national measurement standards, and in that case, cost-effectiveness analysis, a variant of cost-benefit analysis, was recommended for the determination of internal resource allocation within the NML.

Benefits specific to the other criteria were generally positive, although difficult to quantify. Their case-study assessments suggest that their formal quantification and inclusion in the CBA would not have significantly influenced the desirability of the R&D projects evaluated.

A important finding was that cost-benefit analysis, when based on factors internal to CSIRO, was inappropriate to evaluation of CSIRO R&D. The innovations studied involved high degrees of interactions between CSIRO and their industrial collaborators and the *joint* activity was the source of significant productivity benefits to the innovations' users. Separating the returns from CSIRO's publicly-funded investment from those of the industrial collaborator was both difficult and potentially misleading. The preferred benefit-cost ratio was based on the aggregates of the costs and benefits from both private and public investments.

In all four evaluations, the total benefits from the innovation exceeded total costs. In the evaluation of National Measurement Standards, benefits were assessed as greatly exceeding costs but could not be quantified - their diffusion through the community makes the quantification of the counterfactual or control solution virtually impossible. In the other three evaluations, total benefits were found to be in the order of double the community's resource costs.

CSIRO has developed a framework for setting its research priorities. It represents an alternative to prospective CBA for determining the relative worth of competing research proposals. The study found that this CSIRO priorities assessment framework would complement rather than substitute for prospective CBA. In particular, the priorities assessment framework was favoured for broad national direction-setting and for the preliminary screening of research proposals. CBA was favoured for more formal evaluation of well-specified and researched R&D investment proposals.

1. Introduction

1.1 Purpose

This study is an economic evaluation of selected CSIRO research into manufacturing and communication technologies. Its major purpose is to establish an economic methodology useful to the CSIRO researchers for establishing the relative worth of their research in various industrial and service technologies, and for allocating their R&D resources across them. In meeting this purpose, the study is seen to benefit not only CSIRO, but also the nation.

CSIRO has developed a priorities assessment process to guide resource allocation. The BIE research is seen as complementing this work, especially by contributing greater economic focus and quantitative substance, albeit in a specialist field, to the broad approaches established by CSIRO, and by providing some critical commentary on CSIRO's priorities assessment process from the perspective of the case-study material.

1.2 Background

This evaluation of CSIRO's industrial research consists of four case studies jointly undertaken by the BIE and CSIRO over 1990 and 1991. Evaluation criteria were determined jointly by the BIE and CSIRO, with the aim of exploring how well CSIRO research met underlying economic objectives. The four case studies were jointly selected to demonstrate the application of the evaluation criteria over a variety of research.

Research areas were selected so as to present different problems to the analyst and to illustrate where different techniques were needed. For example, a major difficulty in the retrospective studies was assessing the magnitude of productivity benefits experienced by users of the CSIRO innovations. In the prospective evaluation the greatest uncertainty lay in predicting outcomes and their probabilities of success. Project selection is further described in BIE (1990).

The case studies cover R&D from two of the CSIRO institutes - the Institute of Industrial Technologies (IIT) and the Institute of Information Science and Engineering (IISE), and four constituent Divisions, the Division of Chemicals and Polymers (DCP), the Division of Manufacturing Technology (DMT), the Division of Applied Physics (DAP) and the Division of Radiophysics (DR). They are:

- the development of new crop-protection chemicals with Du Pont Ltd under the Dunlena agreement (DCP);
- the development and commercialisation of the CDT pulse welder (DMT);

- the design and development of earth station antennas for satellite communication (DR); and,
- the development and maintenance of Australia's national measurement standards (DAP).

The case studies, neither individually nor as a whole, should be seen as representative of CSIRO's industrial research. The coverage is too narrow especially given the inherent riskiness of R&D projects – many can be expected to fail while, to compensate, the successful ones might generate very high rates of return. The case studies do not compare all outcomes with all resource inputs, and do not constitute a review of the CSIRO.

CSIRO (Stocker, 1990) in emphasising the importance of evaluation, saw different roles for prospective and retrospective studies. Prospective studies were seen as a guide to resource allocation decisions, while retrospective studies were seen as indicating the *effectiveness* of previous projects. These studies can be seen as having such uses – in addition, insights generated might improve future effectiveness. The studies are described in Chapter 2.

1.3 The evaluation criteria

The evaluation criteria, developed by the BIE, are listed in Table 1.1. Although here applied to specific projects, these criteria are equally applicable to broad fields of industrial research. The importance of individual criteria vary according to the application. These criteria are not independent. Their interrelationship means that simply combining them into a single overall measure of R&D would probably double count benefits and give misleading results. The criteria are described in Chapter 3.

1.4 Issues

The case studies contribute to the research base on Australian innovation, and in this way can assist policy-makers concerned with the development and interaction of industry and technology policy. In particular, the case studies may add to the understanding of such current issues for technology policy as the implications of globalisation for national science policies, the relative roles and importance of strategic and competitive research and the appropriate balance of support between the research, development and the commercialisation/marketing phases of the innovation process.

Table 1.1 Evaluation criteria

Criterion	Issue	Evaluation method
1. Benefit/cost analysis	Contribution to social welfare	Quantify directly attributable cost,benefits and social discount rate
2. Commercial feasibility	Commercial prospects	Compile inventory of complementary assets, level of patent and other protection
3. International competitiveness	Contribution to economic growth	Import replacement, export development potential
4. Inter-industry effects	Contribution to competitiveness of other industries	Backward and forward linkages
5. Demonstration effects	Contribution to Australia's reputation or technological sophistication	Awareness of CSIRO contribution
6. Human capital formation	Enhancement of scientific skills of Australian industry	Labour turnover statistics
7. National technological capability	Contribution to technological leadership	New firm creation, bibliometric survey
8. Community benefits	Contribution to community service	Assess non-market benefits

1.5 Implications for CSIRO's own assessment

Over the last two years, CSIRO has developed a priorities assessment (PA) process designed to ensure its resources are allocated to provide greatest national benefit. The CSIRO Executive Committee believed that CSIRO's strategic direction could be determined only against the background of Australia's national research priorities.

The PA process was designed to rank national research purposes. It was seen to fill a gap – no single overall ranking of national research priorities existed, neither was there any well established process for determining such a list. A high degree of judgement is unavoidable in determining national research objectives, but the CSIRO process ensures the judgements are made on a consistent known basis and facilitates the convergence of the individual judgements to a group consensus.

The decision-making method that forms the heart of CSIRO's PA framework can be viewed as a variant of the cost-benefit analysis used in the case-study assessments. One difference is while, in cost-benefit analysis, all factors fundamental to a decision are ultimately collapsed into a *single* quantitative "decision-variable" (ie benefit-cost ratio) , in the CSIRO's PA method the decision factors collapse into ***two*** variables, one essentially scientific/technological in character, termed feasibility, and the other, economic in character, termed attractiveness. In prospective cost-benefit analysis the analyst's judgements on potential technological advance, on market prospects and on their interaction may be hidden from the decision makers: in the CSIRO PA method such judgements are explicitly the responsibility of the decision making group.

Chapter 4 assesses the relationship between the CSIRO PA framework and the evaluation methods used for the case studies.

2. Case histories

2.1 Overview

This chapter briefly describes the individual studies, drawing out salient features which enhanced or hindered project success. The projects are summarised and assessments made on how the benefits to Australia might have been increased.

The chapter provides insight into the relative weaknesses and strengths of various approaches to innovation represented in the case studies. From a historical perspective, it explores such issues as: How was the tactical research underlying each innovation related to the preceding strategic research? What blend of skills and resources was used in the development? When was a commercial partner involved, and what was the nature of the agreement, the cost sharing, the extent of commercial success ultimately enjoyed?

The analysis is contained in four sections:

Genesis: The ability of the researcher to appropriate the returns, eg by patent protection, etc, and to have access to complementary factors to R&D such as marketing networks are important factors in the selection of R&D projects (see Teece, 1986). Were these factors considered at project onset?

Industrial collaboration: Issues covered include: Was the industrial collaborator approached at the opportune time to ensure efficiencies in the overall innovation process? Did the industrial collaborator have the appropriate characteristics, eg financial strength, presence in export markets? Was the contract arranged with the industrial collaborator appropriately made with appropriate commitments?

Innovation performance: Covers the relationship between the research, technology and commercialisation elements of the innovation process, and includes technology transfer issues.

Marketing and sustainability: Analyses the contributions of industrial collaborators involved in the innovation.

2.2 The case studies

All four research projects were successful in achieving market support. However they differed widely in the nature of the R&D and the manner of its commercialisation.

The projects were evaluated by cost-benefit analysis, using the Department of Finance methodology, and a real discount rate of 10 per cent pa. All projects were judged socially beneficial with benefit-cost ratios greater than 1. The projects and the results are briefly described below.

2.2.1 *The Dunlena agreement*

This case study covers research by the Division of Chemicals and Polymers into new crop-protection chemicals. This research is being carried out in conjunction with Du Pont, one of several transnational companies dominating chemical manufacture and marketing. The Dunlena agreement between CSIRO and Du Pont Australia Pty Ltd sets down the arrangements for cost-sharing in research and testing, and for the manufacture and marketing of commercially successful chemicals developed by CSIRO.

Dunlena Pty Ltd was established as a jointly owned company in 1985 to give effect to the agreement. To date no chemicals have succeeded in passing through the innovation pipeline to successful commercialisation. While some chemicals are now undergoing advanced testing, the extent of national benefits will depend on the likelihood of eventual success, the significance of the breakthrough, the breadth of the world markets for the chemical, and on whether Australian manufacture proves feasible.

The evaluation involved prospective cost-benefit analysis, with the risk of failure assessed from Du Pont's continuing financial contribution to the CSIRO research and the return they expect, on average, from commercial investments.

A benefit-cost ratio of 2.1 was calculated for the Dunlena project. In terms of the expected returns to CSIRO's investment, the ratio fell to 1.1. A full description of this research and its evaluation is contained in BIE Research Paper No. 4.

2.2.2 *The CDT synchro pulse welder*

This case study covered the development of a commercially successful top-of-the-range welding unit by the CSIRO Division of Manufacturing Technologies and an Australian-owned manufacturer of welding machines, Welding Industries of Australia Pty Ltd.

The welder design was based on a pulse generator developed by a CSIRO scientist, Dr Ogilvie, in 1979. Agreement between WIA and CSIRO laid the foundation for close cooperation between DMT and WIA in developing a product with commercially desirable characteristics. The CDT[1] pulse welder was marketed domestically by WIA in 1984, and sold overseas two years later. It proved commercially successful, and despite a price premium was still the preferred choice by some exporting manufacturing companies when evaluated by the BIE.

A benefit-cost ratio of 2.2 was calculated for the CDT project. The ratio for CSIRO, including only their royalties as benefits, was 0.1. The ratio of all public benefits,

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[1] Controlled drop transfer.

inclusive of the productivity benefits to Australian industry, to the public investment was 3.6. A full description of this research and its evaluation is contained in BIE Research Paper No. 5.

2.2.3 *Earth station antennas*

This case study covers the development by the CSIRO Division of Radiophysics of antennas used in Australian and overseas earth stations for satellite communication. The design of the antennas and the associated feedhorns is an integral element in earth station design and is considered to be a "clever" part of the design.

The Division's expertise in earth station antennas developed from their work on radioastronomy in the 1960s and 1970s and was used commercially in a range of communication projects from 1978 to the present. Its commercialisation was the result of a close relationship between the DR and OTC, who supported the Australia manufacture of Earth stations both for domestic use and to assist them win international contracts for the export of telecommunication services.

A benefit-cost ratio of 2.0 was calculated for the Earth station antennas project. A full description of this research and its evaluation is contained in BIE Research Paper No. 6.

2.2.4 *National measurement standards*

This case study examined work undertaken at the National Measurement Laboratory (NML) by the Division of Applied Physics on the development and maintenance of Australia's national measurement standards. These physical standards form an integral element of Australia's National Measurement System (NMS), which in turn constitutes the national infrastructure used, *inter alia*, to internationally demonstrate the compatibility and quality of Australian products.

The evaluation, described in BIE research Report No. 9, concluded that the benefits of the NMS far exceeded its costs. However due to the intangible and indirect nature of the benefits and the interconnectedness of the contributions of its constituent organisations, a benefit-cost ratio could not be quantified for the NML.

The report recommended an alternative form of cost-benefit analysis, cost-effectiveness analysis, which allows resource allocation decisions to be made so as to minimise the net cost of achieving a national objective. This method is entirely consistent with the CSIRO priorities assessment method and is particularly suited to the determination of how the responsibilities of the NML can best be met from its limited resources.

2.3 Genesis

In all four case studies, the research that formed the focus of the evaluation was built upon previously established technological capability and expertise. With the exception of Standards, the evaluation was of product development stemming from strategically directed research. However the resources needed and the extent of industry involvement in determining the direction of the research varied between projects.

The **Dunlena** approach to crop-protection chemical research now used by the DCP was introduced after their discovery of cycloprothrin, a new environment-friendly crop-protection chemical. Ultimately the patent rights to cycloprothrin were sold, and the resultant royalties represent a significant proportion of CSIRO's total royalty revenue. Nevertheless, there were reasons to doubt whether all the potential returns to Australia were achieved from the preceding research. Certainly Australian manufacture was not been achieved, and usage in Australia, despite the desirable environmental properties, has apparently been limited to date. The major problem was as identified by Teece (1988), viz the type of appropriability regime faced by the research organisation.

It was partially to overcome these perceived deficiencies that the DCP in their crop-protection chemical research determined to gain access to necessary complementary assets through a cooperative agreement with a transnational chemical company. The DCP was greatly assisted in this by its international reputation and portfolio of patents. The selection of partner was by competitive tendering and negotiation, and resulted in the agreement with Du Pont.

The **CDT welder** had its genesis in 1979 with the construction of a pulse generator mainly designed to permit empirical investigation of metal transfer in plasma arcs and to serve as a tool for solving welding problems encountered by Australian industry. However the potential of this pulse generator as a basis for an innovative productivity-enhancing welder became apparent to its developer and patent-holder, Dr Ogilvie, and action was then taken to find an industrial collaborator.

At the time the role of the DMT was seen as providing intellectual leadership, pushing back the knowledge frontier limiting the development of industrial processes. Responsibility was focussed on the individual rather than through a hierarchical organisational structure. Within this free management framework, Dr Ogilvie had the opportunity to follow his intuition and act as a "product champion" overseeing the CDT's development.

The CSIRO expertise in **antenna** design was established from basic research by CSIRO in radioastronomy in the 1960s. At that time the advent of satellite communication was not foreseen, and no commercial applications were seen for the CSIRO skills. The commercialisation of these skills was only made possible by collaboration in the Australian manufacture of earth stations between CSIRO, OTC and Australian producers of sophisticated mechanical and electronic components used in the manufacture.

Australia's expertise in **measurement research** was established to assist industrial development. Establishing this capability necessitated both assistance from NPL (the UK national measurement laboratory) and considerable investment on the necessary Australian facilities. Because the development of new standards builds upon established "base standards", a certain critical mass is required to maintain the capability. Australia research in measurement has been at the frontier of international research in selected fields, and has enabled Australia to negotiate reciprocal recognition agreements with overseas measurement laboratories.

2.4 Industrial collaboration

The world reputation of the DCP research in crop protection chemicals provided the necessary lever to negotiate a cooperative agreement with a transnational chemical company, and the tendering approach enabled the best fit between their respective needs and capabilities.

Industrial collaboration with Du Pont has offered mutual advantages. It provided Du Pont with access to an additional high-quality source of novel chemicals. It gave CSIRO commercialisation information allowing its research to be better directed towards commercial opportunities. In addition it provided CSIRO with access to Du Ponts' extensive field and environmental testing facilities and ensured any successful chemical discovered would gain access to world markets. The agreement also allowed for Australian manufacture, if commercially and practically feasible.

For the CDT, only WIA, the smallest of three Australian manufacturers of welding equipment, was interested in commercialising the CSIRO innovation. At that time, the early 1980s, the DMT saw its role particularly in relation to Australian manufacturing and did not seek to collaborate with overseas manufacturers. Because CSIRO had not established a reputation at the development end of the R&D spectrum in this field, it is unclear whether they would have been able to attract additional overseas interest, eg from Oerlikon, a European company which owned a minority share in WIA.

OTC and latterly the Department of Defence have provided the commercial support for the antenna research of the DR. By and large, overseas manufacturers of earth stations have their own in-house capabilities for antenna design, or alternatively support specialist national facilities sometimes for reasons of national security. In any event, the cooperation with OTC was critical to the commercialisation of CSIRO skills. The international market in antenna design services is very small and tightly controlled.

The NML have at various times undertaken instrument development with an industrial collaborator as a spin-off activity. They have also provided problem-solving services in measurement to Australian industry. However their main work is the provision, maintenance and development of national physical standards. This is essentially a non-commercial infrastructure service in most countries. It is a service no individual company or business organisation wishes to undertake. Therefore the NML collaborates firstly with its overseas counterparts – in the setting up of new standards and secondly with the other bodies in the Australian NMS – in organising the transmission of measurement standards to industry.

2.5 Innovation performance

Since no crop-protection chemicals have yet emerged from the innovation pipeline – the normal time for development to commercialisation is 7 years – it is too early for a results-based assessment of the innovative process. Progress to date, the advanced testing of some promising chemicals and the continuing contribution of Du Pont to the program does suggest arrangements have been relatively successful to this stage.

Interaction between WIA and DMT was efficient in that the CDT incorporated several novel features. The identification of these features and their successful development was the result of very close interaction between CSIRO scientists and WIA design and production engineers. Moreover this cooperation saw the transformation of the WIA factory to the use of electronics. However appropriate innovation requires balance between research, development and commercialisation expenditures and the evidence suggests that WIA lacked the financial and managerial resources to support the innovation to the optimal extent.

The innovation in antenna design was of an continuing incremental nature involving cooperation between CSIRO, OTC and certain manufacturers. The combination appeared balanced and proved successful although early projections of overseas sales seem over-optimistic.

Research into the measurement of high temperature by the NML led to the development of the PRT bridge, subsequently commercialised by Leeds and Northrup[2]. This innovation led to productivity gain in industrial laboratories. Nevertheless the nature of the NML's work is not primarily geared towards industrial innovation. Their major research contributions has been in improving the accuracy of national physical standards, an area where new standards development is typically in advance of industry's articulated needs.

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2 High-temperature measurement was the particular focus of the BIE's evaluation of NML measurement responsibilities.

2.6 Marketing and sustainability

The prospective nature of the Dunlena evaluation makes assessment of the market impact difficult to assess. A prime consideration will be the nature of the chemicals discovered.

In the case of the CDT, the evidence suggests that the ongoing product support and upgrades needed to ensure continuing sales success were slow. The CDT certainly contributed to the overall market image of WIA's product range and to their profitability. Nevertheless it appears that the company did not have the resources to establish a sufficiently large (international) market to justify the expenditure to remain competitive. It is questionable whether the initial market position will be sustainable in the longer run.

The future of the DR work in earth station antennas is uncertain. Technological change has seen optical-fibre technology emerge as a competitor, although in certain communication fields, microwave communication will remain the dominant technology. Newer satellite technology has enabled the size of the earth station antennas to be reduced, a change away from Australia's present competitive advantage. Nevertheless OTC is continuing to make new sales of Australian-designed antennas, and in any event the design capabilities at the DR is being directed towards new potential commercial opportunities, eg TV payphones, mobile communication, etc.

3. Evaluation criteria

This Chapter describes how the evaluation criteria (Table 1.1) were applied in the case-studies and reports on their usefulness, both for retrospective evaluations and for prospective priorities setting. It provides a basis for the comparison, in the next Chapter, of the CB and CSIRO PA frameworks.

Social *cost-benefit analysis* was considered the most important of the criteria. In a hypothetical world of perfect costless information, it would be the key and possibly only criterion – all others would be encompassed within it. Dollar values could be attached to any social benefits spinning out from the R&D, thus allowing all spin-off benefits -- including those separately covered by the other evaluation criteria (eg international competitiveness, inter-industry and demonstration effects, human capital formation and community benefits) -- to be collapsed into a single dollar-valued decision criterion. Moreover decision-makers' judgements, eg concerning risk assessment, could be systematically built into the process ensuring consistency in choice; and their uncertainties also incorporated thereby providing information on the expected dispersion of the selected benefit-cost criterion about its average.

However, as discussed in Section 3.1, social CB analysis, in its most conventional form, was found inappropriate for the case-studies and a "total " form that aggregated private and public benefit and expenditure flows was adopted. One advantage of the total approach was in comparing the R&D benefits arising after commercialisation by an industrial collaborator with those arising from institutions with social responsibilities. The different characteristics of the benefits that arise in the two situations are described in Sections 3.1.1, *commercial feasibility*, and 3.1.2, *community benefits*.

A particular advantage found for the cost-benefit framework was the built-in safeguards against double-counting of benefits. In all case-studies, the benefits associated with the *national technological capability* criterion (Section 3.2) overlapped with some of those considered under the other evaluation criteria (Section 3.3) viz *international competitiveness, inter-industry effects, human capital formation, demonstration effects.* The contrast between the stock-type nature of national technological capability and the flow-type benefits associated with the other evaluation criteria emphasised the nature of the double-counting.

3.1 Benefit-cost criteria

The benefit-cost criteria – eg present value, BC ratio, internal rate of return – are estimated by valuing the impacts of R&D on affected individuals and firms and comparing the sum of these values to the government outlays necessary to generate them. The methodology is well known, and described for example in Department of Finance, 1990.

Difficulties were experienced in applying social CB analysis to public sector R&D. Some of these difficulties were associated with the non-linear[3] nature of innovations studied. If the innovation processes had proceeds linearly through the research, development and commercialisation phases, with each phase being complete in itself and separate to the other phases, then it might have been possible to attach a value to each of the phases. In particular, if the market for the property rights to new research had approximated the economic ideal, with full information freely available to all parties, with no costs in completing transactions, with many buyers and sellers, with perfect appropriability, etc, then the sale price received for the property rights could have been used in the cost-benefit analysis to value the R&D. Under these conditions, the price received by CSIRO for the rights to their research could have been taken as a measure of its social value[4]. The BC ratio would then have simply approximated the ratio of CSIRO returns to their outlays.

If CSIRO had selected R&D projects on the basis of the expected returns from auction of intellectual property rights, it is possible that none of the four case-study projects would have been undertaken – despite the findings, detailed in Chapter 2, that all were of net social benefit. Ratios of CSIRO returns to outlays, all suitably discounted and converted to real present value, are less than one in all cases:

- for the CDT welder, royalties represented only about 10% of CSIRO costs;
- for measurement standards, cost recovery from calibration service charges[5] falls far short of the cost of maintaining the standards at internationally accepted levels;
- no returns to date have been made under the Dunlena agreement. Moreover it is possible that the market might value CSIRO's equity in the project's present assets, particularly unproven crop-protection chemicals

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[3]The linear model of R&D in which the innovation proceeds in turn through separate research, development and commercialisation phases has been rejected. Researchers have found that because of the considerable feedback between these phases and considerable cross-institutional collaboration and sharing/trading of information, the simple linear model will lead to misleading and erroneous policy prescriptions.

[4]The validity of this assumption would depend on how closely the various markets associated with the R&D approximated the ideal market - the degree of error involved could vary widely from case to case. If the price received by CSIRO was considered to be below the expected value of the private returns it could generate, then there may be some implicit subsidisation of industry by CSIRO.

[5]Although these are at a level consistent with those charged overseas and in some cases represent revenue-maximising levels.

now in the innovation pipeline, as less than the present value of CSIRO's outlays;

- although antenna design services to OTC and DoD are now charged at economically efficient rates, ie marginal cost, overheads are not fully recovered.

The methodology described above was unsuitable, in part because the linear model of innovation does not fit many of CSIRO's industrial research projects. Such projects, including the ones studied, are jointly undertaken with private firms - in recognition that successful innovation requires early collaboration between the researchers and the potential users. In the case studies, the distinction between private and public benefits was so poorly defined that an alternative measure of the BC ratio, viz the ratio of total public and private benefits to total public and private resources used, was considered most useful.

An example of this difficulty for conventional social BC analysis was the treatment of the productivity benefits generated in Australian industry by the CDT pulse welder. These benefits were the outcome of innovation jointly generated by WIA and CSIRO. If all productivity benefits had been allocated against public (CSIRO) expenditure, the resulting social benefit-cost ratio of 3.6 could be an overstatement. Given the joint nature of the innovation, it seems fairer to use a total benefit-cost ratio, calculated by dividing the sum of the social and private benefits by the sum of the total (private and public) resource costs. This total benefit-cost ratio was calculated at 2.2 and was preferred to the 3.6 estimate.

It has been argued, eg Freebairn and Gannon (1986), that since much private-sector R&D also generates productivity benefits, the level of funding for public-sector R&D projects should not be set in accord with the levels of social benefits they produce. Rather public funding to socially beneficial R&D projects should be limited to that necessary to ensure their commercial viability. If a "minimum public funding" criterion were to be applied to evaluate the case-study projects, the evidence suggest at least three projects might have been accepted.

A necessary condition to meet such a criterion was that CSIRO negotiate the best possible deal on behalf of the public with any industrial collaborators. Although determining whether this was difficult, it appeared that the commercial arrangements made with WIA in the early 1980s were overly generous[6]. On the other hand, the more recent Dunlena arrangements made with Du Pont appeared appropriate. Charges for standards calibrations and antenna services have been increased in recent years in line with a greater commercial emphasis within CSIRO.

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[6] Even after allowing for the possibility that due to the limited resources available in WIA, the CDT project may not have been successful with lesser CSIRO up-front support.

A second difficulty in applying CB analysis to the R&D projects was estimating the dollar value to the nation of effects such as a gain in competitiveness, the demonstration effect, human capital formation and spin-off community benefits, discussed separately below. In principle, BC analysis can generate a quantitative measure of total social benefit. In practice the values of many "benefits"[7] (eg the public provision of national standards by the NML) proved impossible to quantify. Therefore the benefits from those effects were considered as a separate evaluation criteria.

Various other judgements were made in determining the benefit-cost ratios, some less controversial than others. After considering the issues involved in the choice of discount rate, a 10 per cent real discount rate was chosen, a significant factor in the choice being possible competition with industry[8] for R&D resources. However to assist comparison with other cost-benefit studies of CSIRO research, benefit-cost ratios were also calculated using a 5 per cent discount rate. These were not more favourable for the earth-station antenna project because early R&D expenditures generated more substantial benefits than latter ones (Table 3.1).

Table 3.1 Sensitivity of benefit-cost ratio to discount rate

Project[a]	Benefit-cost ratios with discount rates of:	
	10 per cent per year	5 per cent per year
The CDT pulse welder	2.2	2.3
Dunlena crop-protection chemicals	1.1 to 2.1[b]	1.7 to 3.8[b]
Earth station antennas	2.1	2.0

Source: BIE Research papers Nos 4, 5 and 6.
Notes:
a No benefit-cost ratio was calculated for the National Standards project – cost effectiveness was preferred as the decision rule.
b The lower value is that for CSIRO alone. By excluding productivity benefits this might understate the national benefit-cost ratio. The higher ratio is for the Dunlena partnership. This might overstate the national benefit-cost ratio.

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[7] Negative as well as positive ones.

[8] When R&D outcomes are subject to high uncertainty, and particularly in prospective evaluations, the discount rate can be increased to include a risk component. To sidestep the major difficulties that uncertainty poses for traditional cost-benefit analysis, a variant called risk-benefit analysis is sometimes used (See Annex A4.1). Uncertainty is further discussed later in this Section.

Potentially more controversial was the preference for the orthodox approach[9] of valuing revenue and costs by using domestic prices - as advocated by Department of Finance (1990) and UNIDO (1989) --- to the Little Mirrlees approach of using world prices -- as advocated by the OECD (1989). By taking account of the assistance effects, the Little and Mirrlees approach discriminates against R&D for an industry with a relatively high level of effective assistance, while the orthodox approach would not. In the case studies, the choice of approach was significant for only the CDT project. The very high levels of effective assistance afforded both manufacturers and users of welding equipment inflated the productivity gains in using industries and the profits of the manufacturer, causing the orthodox BC ratio of 2.2 to greatly exceed the 1.6 calculated by the Little-Mirrless method. After taking account of the ongoing flattening of the assistance regime (the so-called "level playing field" policy), which has reduced the differences between the methods, the more straight-forward orthodox approach would appear adequate for CSIRO use in industrial R&D evaluation.

Table 3.2 Sensitivity of benefit-cost ratio to CB method

Project[a,b]	Benefit-cost ratios	
	Orthodox	Little Mirrlees
The CDT pulse welder	2.2	1.6

Source: BIE Research papers Nos 4, 5 and 6.
Notes:
a No benefit-cost ratio was calculated for the National Standards project – cost effectiveness was preferred as the decision rule.
b Different levels of assistance were not at issue in the Dunlena or Earth station antenna research.

Generally the judgements applied in the cost-benefit calculations were conservative. Thus in the case of future net revenue flows expected from sale of Earth station antennas to centrally planned economies, a risk factor of 5 per cent per year was added to the discount rate. In the case of the pulse welder, the productivity benefits to industry were assumed to flow from faster dissemination of the benefits of the new technology, partly because of the confidence of the widespread welding shops in the CSIRO-promoted technology and partly because of its availability on the Australian market earlier than if there had been reliance on overseas R&D, and thus of limited duration.

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[9] This builds in the effect of domestic policy distortions.

A conservative approach was also adopted in the assessment of the returns available in the event of a successful crop-protection chemical or chemical family being developed by Dunlena - the returns could vary widely depending on the properties of the new chemical and the time taken before discovery. Such *uncertainty* is typical of the prospective evaluation of R&D proposals, where it can represent a major hurdle to robust and reliable quantification of decision criteria. In evaluating of the Dunlena project, a single benefit profile, with an initially low level of benefits increasing with market penetration, and two cost profiles were used. A low-cost early-discovery profile was supported by arguments from the CSIRO DCP but the more conservative high-cost late-discovery profile was preferred for the case study. The considerable sensitivity to the choice of assumption is shown in Table 3.3.

Table 3.3 Sensitivity analysis for the Dunlena project

	Successful outcome			Average outcome	
	Net present value $M	Benefit /cost ratio	Internal rate of return	Net present value $M	Benefit /cost ratio
DUNLENA					
Conservative: high cost, 10% disc	156	4.2	32%	38	2.1
Low cost 10% discount	163	7.0	36%	21	2.1
High cost - 5% discount	298	5.9	32%	98	3.8
Low cost - 5% discount	324	10.2	36%	107	5.0
CSIRO					
Conservative: high cost, 10% disc	19	3.2	23%	1.0	1.1
Low cost 10% discount	41	5.7	30%	8.7	2.0
High cost - 5% discount	42	5.0	23%	7.8	1.7
Low cost - 5% discount	84	8.9	30%	22.4	3.1

Source: BIE Research paper No 4.

The variations in the benefit-cost criteria estimated for the Dunlena project are not fully indicative of the uncertainty attaching to the case-study estimates. In each of the studies considerable data problems were experienced, particularly relating to private returns. In the event, the best available data was used, and conservative assumptions used to adjust it for risk etc. Particularly in the case of the Dunlena and Earth station antenna projects, the benefit-cost ratios should be regarded as the best available pending better data[10].

3.1.1 Commercial feasibility

Commercial feasibility analysis[11] is used by private concerns, ie CSIRO's industrial collaborators, to rank alternative investments. However such analysis differs from the cost-benefit analysis of the case studies, which recognised that the social value of outputs could differ from their market prices, and took into account distortions and spill-over effects. Nevertheless commercial returns are a component of the "total" benefit-cost calculations discussed above. Commercial feasibility is included separately as an evaluation criterion for two reasons.

First lack of commercialisation of CSIRO research has been seen as a policy issue[12], and various mechanisms have now been set up to remove impediments and reduce costs of commercialising research. Commercialisation is a consideration in the choice of projects and the way they are implemented. The importance of commercialisation depends on R&D generating higher returns when commercialisation is a consideration from the start of the project[13].

Secondly, the project outline[14] drew attention to economic research which indicated that the ability to maximise the economic benefits from public R&D could vary between projects according to the appropriability regime and access to complementary assets (Teece,1986)[15]. In the retrospective case studies, the power of such factors to explain relatively low returns from public sector R&D was assessed.

CSIRO's rationale for establishing Dunlena provided an excellent example of an innovator overcoming a fundamental obstacle to achieving commercial returns from an innovation. CSIRO's Fine Chemical Program needed access to expertise in fields of market information, testing capabilities (especially those facilities needed for toxological examination), the provision of data to government regulatory authorities, and access marketing and distribution channels. The selection of Du

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[10]High levels of uncertainty are typical of prospective benefit-cost analysis.

[11]Using discounted cash flow techniques to estimate private net present benefits.

[12]See for example BIE Research Report No. 32 Commercial Opportunities from Public Sector Research.

[13]The case for commercialisation was strongly advanced for CSIRO research into crop-protection chemicals. It is widely believed that the returns to Australia from CSIRO's discovery of Cycloprothrin would have been increased if arrangements similar to those now current for Dunlena had been in place. Conversely the national returns expected from the current research of the DCP would be considerably lower in the absence of the Dunlena agreement.

[14]See BIE Working Paper No. 68, *Evaluating CSIRO's industrial research: the evaluation framework.*

[15]The importance of the appropriability regime and of access to complementary assets is recognised in the CSIRO priorities assessment process through the factors determining attractiveness.

Pont as its partner greatly enhances the prospects for and extent of a commercial return from CSIRO work, and at the same time enhances the prospects for net social benefits.

In contrast, the character of the CDT commercialisation explained its failure to achieve higher returns for Australia. Commercialisation on the domestic market was successful to the extent that it established a niche for itself in competition with cheaper imported welding units. However it was acknowledged that greater penetration of the domestic market might have been possible with greater investment in commercialisation and a more mission-oriented approach. More importantly neither of the joint partners had the facilities necessary for successful world marketing.

In the Earth station antenna project, the successful commercialisation of the CSIRO research was found to be critically dependent upon the active partnership between CSIRO, OTC and the Australian suppliers of sophisticated components.

3.1.2 Community benefits

Community benefits incorporate those non-pecuniary benefits of CSIRO research which are often important (and at times can over-ride the purely commercial objectives as instanced for example in some of the work of the CSIRO Institute for Natural Resources and the Environment). For example, the research on water and sewage treatment by the Division of Chemicals and Polymers has obvious community benefits[16], which while economic in the broad sense that they are of value to a community, are not commercial since they are not covered by markets.

CSIRO research into industrial and communication technologies has a strong business orientation, and the generation of any returns depended critically on its commercialisation. To that extent, research leading to products that met the community's need for safer and cleaner environment might also have had a commercial objective. Nevertheless there were instances when the environmental effects of CSIRO research were only partially captured, if at all, in the price paid for the product or service. In these cases the community benefits were spill-overs, which should have been separately valued and added to the pecuniary returns.

These non-pecuniary benefits were identified in the CDT pulse welder project (lower fume generation and greater energy efficiency), in the Earth station antenna project (radioastronomy), and might be generated by successful Dunlena chemicals (as higher-quality rural produce which exhibit lower levels of toxicity, as reduced toxic run-off into rivers and as lower residues in soil). However the

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[16]Eg, reductions in the levels of pollutants in areas of natural beauty, such as rivers and coastal stretches.

magnitude of such benefits were assessed as second order in these projects, and hence not a factor supporting the investment decisions to undertake the R&D.

In contrast the major benefits of the national standards capability derived from its support of Australia's national measurement system, an essential but non-commercial element of public infrastructure. Moreover some of the particular work of the NML was directed towards social outcomes, for example work in the acoustics standards area had the ultimate objective of reducing noise-induced hearing loss.

Although techniques for the measurement of non-pecuniary spillover benefits do exist (eg by contingent valuation techniques), it was unnecessary to use them for the NML case study. The essential nature of the NMS dictated its retention. The critical issue was then to evaluate alternative means of generating these benefits, selecting as optimum the method with the lowest social cost. This form of evaluation, viz cost-effectiveness analysis, was recommended for resource allocation within the NML and the NMS.

3.2 National technological capability

National technological capability, unlike the other criteria, could not be directly measured as a *flow* of outcomes from investment in R&D. Rather national technological capability was considered to represent the *stock* of know-how residing in CSIRO, other scientific institutions and industry. This stock of know-how can be drawn on to generate future income. It can also be added to. If not updated, it may, like private physical capital, become obsolete with time, losing the capability to earn income and becoming worthless. Like some forms of public capital, eg national defence infrastructure or a clean environment, the stream of benefits it generates may be hard to value.

In all case studies, it was assessed that the stock of know-how had been increased during the project. This increment to technical capability was accumulated partly as human capital formation (included as a separate criterion), partly as organisational-specific knowhow and partly in other form of information storage. At the same time, all projects drew on existing technological capabilities, often built up by non-commercial strategic research. Placing a values on the increments to the stock and a charge on the use of existing stock was beyond the scope of the case studies, but the evidence suggested that any net positive effect might be small.

In all four case studies, the technological expertise and capability at the CSIRO represented a springboard for innovative activity and also generated spillover effects of increasing the private component of Australia's national technological capability. Nevertheless the net increment was found to be small in the four case-study projects.

3.3 Other evaluation criteria

The remaining evaluation criteria can be directly assessed as a flow of benefits. Their importance varied between the different case studies. These benefits were sometimes generated by economic linkages, eg intersectoral linkages. In other cases the mechanisms were not be economic, eg the information flows associated with demonstration effects[17]. The latter benefits would be captured, not by the researcher but by society at large. Thus, for example, investment in industry using R&D intensively and employing leading-edge technology would be less than socially desirable if some of the benefits flowing from the investment accrue to other possibly competing organisations which find it more cost-effective to bid away workers from the leading-edge firm than to fund their own training[18].

The evaluation methodology used in the case studies focussed on the economic rather than the scientific importance. To this extent the views of industry were sought on the usefulness of the research, and to what extent it represented a breakthrough leading to productivity improvements. Since the rights to exploit CSIRO industrial innovations were exclusively held, care was taken to seek the views[19] not only of the manufacturing firms holding the rights and their clients, but also their competitors and firms not adopting the new technology. In this way, a balanced perspective as to the contribution from the CSIRO research projects was sought.

3.3.1 International competitiveness

Increasing the international competitiveness of Australian manufacturing industries is a key objective of CSIRO research. Increased competitiveness can result from either of two mechanisms: the catch-up mechanism which is appropriate when Australian technology lags overseas technology; and the first-mover mechanism which could see Australian industry first to use new technology. In the former case, the CSIRO role could be to increase industry awareness of foreign technology or to adapt it to suit Australian conditions.

Productivity gains estimated in cost-benefit analysis of the CDT welder indicated this project contributed to international competitiveness through both mechanisms. However this productivity effect was actually included in the cost-benefit analysis, and therefore not of additional national value.

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[17] See BIE (1991a) for networking as an alternative form of allocation to the market and firm.

[18] As is the case in the human capital and demonstration criteria.

[19] The relative weight given to opinion depended on the support provided by corroborating evidence.

A gain in international competitiveness might be indicated by improved export performance[20]. However present exports of earth station antenna and expected exports of successful Dunlena chemical would form the basis for their commercial success, and estimates of these direct benefits were included in the cost-benefit criteria.

The presence of exporting benefits additional to those covered in the cost-benefit analysis depends on firstly whether Australia's exchange rate is at an equilibrium level and secondly on whether exports generated by CSIRO research create dynamic spin-off benefits such as the formation of complementary assets that Australia lacks - especially marketing and distribution. Such issues were considered in the case studies, where such effects when present were found to be second order in magnitude.

3.3.2 *Inter-industry effects*

Forward linkage effects arise when an increase in efficiency or quality of output in one industry is passed on as inputs to other industries. Backward linkage effects arise when activity in one industry stimulates activity in industries that produce inputs to the first industry.

Although small inter-industry effects were present in the case studies, in none did they add to the criteria already discussed.

3.3.3 *Human capital formation*

The capability of persons engaged in the development, manufacture or use of any products from CSIRO R&D is likely to increase. This increased capability would, in part, be reflected by increased productivity in the workplace and recognised by increases in earnings. It represents an increase in human capital. Nevertheless the existence of public benefits from human capital formation require that R&D-generated increases in human capital exceed the increases that would have been generated in the absence of the research.

The case studies estimated increases in human capital, but in no case was the public benefit deriving from human capital formation found to be significant. Spillover effects and productivity increases were assessed as alternative sources of social benefits associated with human capital formation were . However the manufacture and use of the products deriving from the case-study R&D was not demonstratably leading-edge and so considered unlikely to generate industrial

[20] In the broad sense that exports, whether accruing from domestic or off-shore manufacturing facilities, contribute to Australia's foreign exchange earnings.

spill-over effects. Spillovers at the work-leisure interface[21] were also considered negligible.

3.3.4 Demonstration effects

One aspect of the concept of demonstration effect is that CSIRO collaborations with Australian firms in an industry may lead other firms in that industry to recognise that Australia has the scientific and engineering expertise to move into a previously underdeveloped area. Such an effect may occur at either the research or manufacturing level.

No clear evidence of significant demonstration effects were found in any of the case studies.

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[21]This increased productivity (deriving from installation of technologically advanced equipment) is often associated with improvements in the workplace environment. The gain in the employee's human capital, particularly the gain associated with quality-of-life aspects, (eg reduced stress), can be of benefit in the employee's non-work human relationships, and to society. Benefits derived by the employee's leisure time colleagues and family are unlikely to be fully appropriated by the employee, and so are external to the employer-employee contract.

4. CSIRO's priorities assessment framework

4.1 Introduction

Cost-benefit analysis, although firmly rooted in economic theory, is used as a practical tool to assist decision makers allocate public resources for national benefit. The CSIRO priorities assessment framework was developed to fill a similar purpose, to assist allocate R&D resources for national benefit. This chapter examines, from an R&D perspective, the relationship between these two frameworks and the extent to which they complement or overlap.

The experience of the case studies suggests that formal quantitative cost-benefit analysis is best applied when its informational requirements can be met – that is it at a late stage of research when more detailed analysis is needed to support investment. It would be least suited for identification of broad areas of research opportunity or initial screening of early research proposals.

4.2 Ranking by broad research purpose

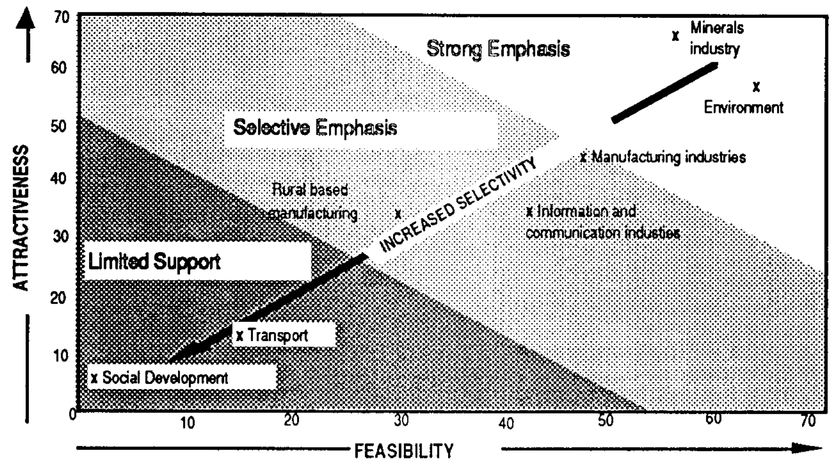
The priority assessment framework was developed by CSIRO to guide decisions on resource allocation between broad research fields. Research, categorised in accord with the Australian Bureau of Statistics (ABS) classification of socio-economic objective (SEO), was ranked in terms of national benefit as determined in the priorities assessment framework. CSIRO's strategic direction was determined against the background of these national research priorities. The validity of the CSIRO framework derives not only from its grounding in industrial and economic statistics, but also from CSIRO's ground-floor knowledge of research opportunities and its leadership in promoting technological change. The findings of CSIRO's priority-setting exercise were applied in a tops-down fashion to ensure internal resource movement was in accord with the determined strategic direction.

The processes used by CSIRO to identify priority areas for the period 1991–92 to 1993–94 have been detailed (CSIRO, 1990, 1991a,b,c). CSIRO used a two dimensional *"Return to Australia"* screen (Figure 4.1) to rank the desirability of prospective R&D in support of national research purposes as a function of:

- a *technical* factor termed **feasibility**
  (the vertical axis of the "returns" screen); and,
- an *economic* factor termed **attractiveness**
  (the horizontal axis of the "returns" screen).

The construction of the feasibility and attractiveness factors is illustrated in Figure 4.2, and discussed in detail in the next Section.

Figure 4.1 CSIRO's *Returns to Australia* screen



Source: CSIRO (1991a)

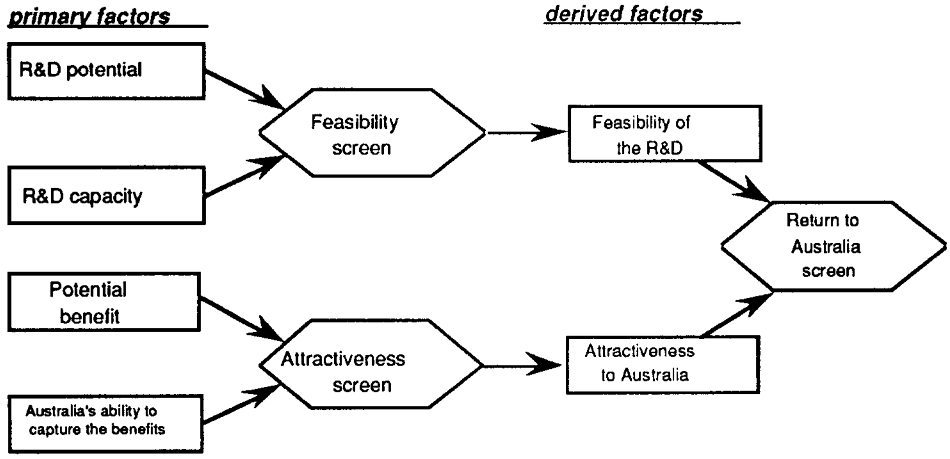
A ternary classification (strong emphasis, selective emphasis, limited support) is used to describe appropriate response – first at the national level and subsequently for the CSIRO role.

This ternary classification illustrates that that even those national research purposes which are ranked very low by CSIRO in both the attractiveness and feasibility dimensions, eg Social Development and Transport, might include a few research projects which could yield very high benefits to Australia and which Australians might benefit from supporting. However, in terms of the total (private and public) research effort, these two research fields would warrant limited support.

Conversely the high levels of national benefit attached by CSIRO to "Minerals industry" and "Environment" research do not mean all projects in these fields are desirable.

The returns to Australia screen is not necessarily indicative of CSIRO's priorities. For example, the strong emphasis on "minerals industry" research could be met through high levels of private sector research. In such an event, the need for a substantial Government (or CSIRO) role would be obviated.

Figure 4.2 The priority assessment factors



Source: CSIRO (1991a)

The ranking of national research purposes could alternatively be based on *prospective cost-benefit analyses*.. CBA is a well-established general-purpose tool used to rank wide-ranging public investment proposals. Thus, despite some subjectivity and possible lack of uniformity in its implementation, CBA is an appropriate benchmark against which to assess the CSIRO priorities assessment framework for R&D. At issue are implementation and outcome differences, eg are the rankings generated through the CSIRO process likely to differ systematically from those of CBA?

Three major differences are immediately apparent. First the quantification processes, used in prospective cost-benefit analysis to collapse the relevant decision data into a single decision variable, work best on specific well-defined projects. Its extension to the prospective evaluation of broad research fields is likely to be costly and possibly lack the sensitivity to be conclusive.

- The *CBA* rules, although well established, suffer firstly from the intense effort, time and cost required for their proper application and secondly from the imprecision unavoidable in comparing national benefits from public research in fields as diverse and broad as the environment and manufacturing technology. CBA is not well-suited to R&D direction setting.
- The rules deriving from the *CSIRO national priorities exercise* are simple and cost-effective. Having established a national or corporate research direction, the operational rules to give it effect and the procedure to evaluate its success are straight forward. Moreover the tops-down application of the priorities assessment framework within CSIRO ensures a consistency of assumption not always a feature of CBA studies undertaken by different

practitioners. This simplicity of the priorities assessment approach comes at the cost of the rigour and quantification potentially possible in CBA.

Secondly the use of the two-dimensional screen in the CSIRO PA method contrasts with the single ranking of CBA. Relative to CBA, the CSIRO PA method has:

- the advantage of visually indicating whether an inability of Australia to derive benefits from a research area is particularly constrained by either technical or economic factors; and,
- the advantage that the two factors are combined according to the best collective judgement of the decision makers, who also take responsibility for these judgements at a corporate level. On the other hand, the way in which the factors are combined is not well defined and might not coincide with a theoretically based CBA[22].

Thirdly the processes associated with the methods are inherently different.

- In cost-benefit analysis, the process is essentially controlled by the technical analyst, even though the judgements on the particular methodology and on values for critical parameters might be determined by the decision makers who are ultimately responsible for the decision.
- The CSIRO process is under the collective control of the decision makers. Various techniques are used to ensure all their relevant experience and knowhow *is made available* to the group (eg debate between product champions and advocates of outlier solutions) *and assimilated* (the DELPHI technique). The lack of formal adherence to the theoretical principles of CBA might be offset by the other properties of this R&D direction-setting process (ie consistency, use of all relevant information, and the close relationship between decisions and their implementation).

At this broad level CBA, rather than representing a competing substitute to the CSIRO direction-setting framework, appears to complement it. CBA can contribute to the CSIRO framework by providing first economic principles to guide the decision makers in their priority-assessing deliberations, and second a support, verification and back-up capability.

4.3 Feasibility and attractiveness

The attractiveness and feasibility measures used in the *"Return to Australia"* screen are each derived from a further two factors: one indicating potential, the other indicating the ability to capture or realise that potential. Combining these "potential" and "realisation" factors are integral elements of the group process

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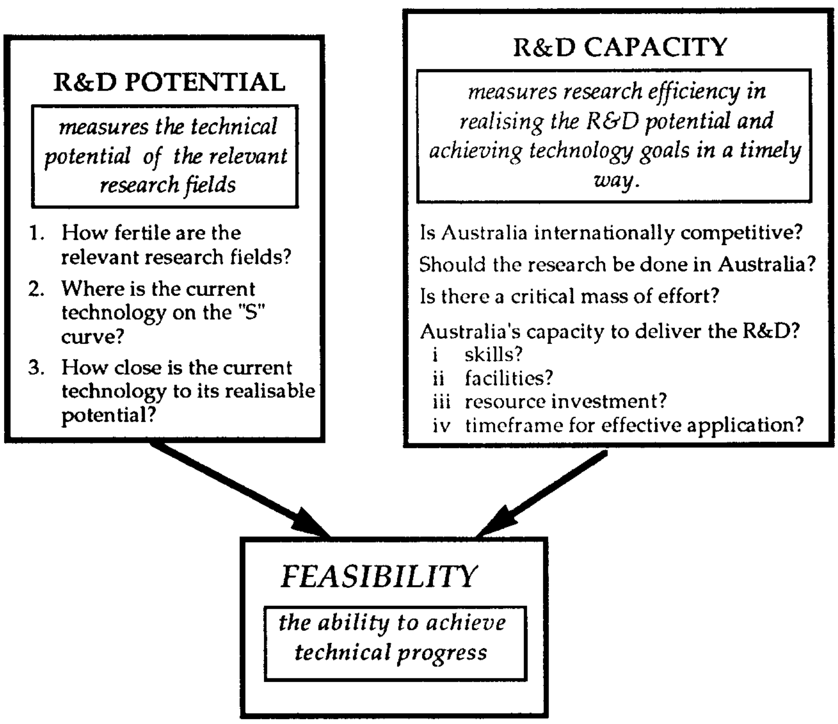
[22] DPIE/CSIRO (1990) attempt to demonstrate an equivalence between the prescriptions of the CSIRO priorities assessment practice and a theoretical-based cost-benefit analysis.

which determines the *Return to Australia* . The process focuses the decision-makers' attention on the factors described in Figure 4.2. The combination of these factors, through three two-dimension screens, is a CSIRO innovation designed primarily to assist in internal planning.

Feasibility and attractiveness, appropriately defined[23], can be combined to form the cost-benefit criteria. In particular, multiplying attractiveness (the dollar value of benefits per unit of technological change) by feasibility (technological progress per dollar of R&D investment) yields the benefit-cost ratio.

The factors used by CSIRO to determine feasibility are detailed in Figure 4.3. R&D potential, the vertical axis of the feasibility screen[24], depends on the fertility of the field, both in terms of its technological diversity and depth. R&D capacity, on the horizontal axis, depends on technical capabilities within Australia.

Figure 4.3 Factors determining feasibility



Source: CSIRO (1991a)

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[23]Appropriate definition is possible in the context of the IRI technique discussed in Section 4.4.

[24]For an example of a feasibility screen, see Figure A4.1.

Figure 4.4 Factors determining attractiveness

POTENTIAL BENEFITS

measures the likely benefit of successful research – can not be controlled by the research body

Commercial

1. Relative importance of technological factors in improving industry performance?
2. Size of market?
3. Contribution to increased productivity?
4. Projected market growth?
5. Exports, import replacement?
6. National benefits through flow-on effects?

Non-commercial

7. Avoided damage?
8. Enhanced social amenity?
9 Health and safety improvements?

AUSTRALIA'S ABILITY TO CAPTURE BENEFITS

measures the efficiency of technology transfer and adoption relative to the ideal of complete capture of potential benefits by Australia. It reflects the ability of Australian companies and organisations to convert technical progress into commercial and social returns.

Commercial

1. Can Australian users compete internationally?

2. Is the technology, socially and politically acceptable?

3a. Can local industry /other users exploit the full potential of the technology in a timely way?

- i is the application uniquely Australian?
- ii linkages with leading companies, enterprises?
- iii adequacy of skills/investment base?
- iv access to international and marketing networks?
- v risks of competitive leakage?

and, if not,

3b. Can substantial benefit be retained?

- vi probability/risks of creating new enterprises?

Non-commercial

4. Is acceptance/implementation of relevant "non-commercial" research by public sector bodies likely?

ATTRACTIVENESS

the likely benefits of successful research

Source: CSIRO (1991a)

In particular CSIRO sees the potential to achieve significant technological progress (R&D potential) as depending on the dynamics of technical change in that particular technology. This can be graphically described in terms of the characteristics (slope, height, position) of the "S-curve"[25]. Other things being equal, R&D managers might favour concentrating on research into technologies experiencing rapid change with distant horizons.

Factors underlying attractiveness are listed in Figure 4.4. Most of these factors were explicitly covered in the BIE case-study evaluations. Contributing to potential benefits – the vertical position on the attractiveness screen are productivity benefits, exports and flow-on effects. The international competitiveness of Australian companies and their access to marketing networks are seen by CSIRO as determining Australia's ability to capture the benefits (the horizontal axis).

The size of the market for the technology is a critical factor in determining attractiveness. Incremental change in a technology that contributes significantly to a nation's welfare might generate greater benefits than a major breakthrough in a technology of marginal importance to the nation[26]. Thus placing R&D resources into technologies that are presently of national importance, or might be expected to be so in the near future, would be favoured other things being equal.

The ranking of projects to generate the most desirable allocation of Australia's and CSIRO R&D resources[27] is determined as the net effect of the feasibility and effectiveness factors. There may be trade-offs, for example, between S-curve and sector size effects. The priority assessment process aims to combine judgements from a range of experts as to the appropriate balance of the underlying factors, and to do so efficiently and consistently and in a way that generates robust and reliable rankings.

The assessment of the manufacturing research purpose and the corresponding CSIRO role, as was determined by CSIRO using the PA framework, is summarised

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[25]The "S-curve" is described in Appendix 3 to CSIRO (1991a). As total R&D effort on a particular technology accumulates, ç (vertical axis) is initially low, then increases with increasing rapidity, until, as the technology's limits are reached, the rate of increase slows. This traces out an "S-curve" on the R&D effort–R&D effort graph. The technological progress per unit of R&D effort (the slope of the "S-curve") peaks where the "S-curve" is steepest, arguably about midway between the technology's infancy and maturity.

[26]This important point is graphically demonstrated in CSIRO (1991a, figure 5, p6). CSIRO compares the potential benefits from a slow-growing large industrial sector with those from a fast-growing, but small, sector.

[27]CSIRO's optimum portfolio of R&D projects might reflect, not only overall projects rankings, but also the desirability of having projects that contain a range of risk factors and return characteristics.

in Box 4.1. In terms of national research purpose, manufacturing[28] was ranked below minerals: in terms of CSIRO's strategic direction it was accorded a lower priority than environmental research.

BOX 4.1

THE ASSESSMENT OF MANUFACTURING RESEARCH

Attractiveness: manufacturing research was rated average as a socio-economic objective – the government's microeconomic reform, measures to encourage improved technology performance, etc were expected to improve the international competitiveness of manufacturing industry and so increase the payoffs to research.

Feasibility rated a mid position on its scale. *Potential benefits* of research were considered high, but Australia's ability to capture them was limited by the high level of involvement of multinational firms and various institutional arrangements. Australia's *R&D capacity* is high in selected areas with established internationally competitive research groups and an established infrastructure.

The **overall rating** on the **"return to Australia"** screen was selective emphasis.

The **role for manufacturing research within CSIRO** was to be *highly selective*, requiring external funding at the target level and only selecting projects which specifically address the ability of Australia to capture the benefits of the proposed research. This reflected CSIRO's and Australia's capabilities.

Various quantitative data were used – including the Manufacturing sectors' contribution to GDP, its trade orientation and its research intensity.

4.4 Assessing returns on R&D investment

The above discussion demonstrates some of the advantages of the priorities assessment framework over cost-benefit analysis in determining national priorities for broad research purposes[29]. A further issue, discussed below, is the relative advantages of prospective cost-benefit analysis and the priorities assessment framework for ranking specific R&D investment opportunities. Within CSIRO Divisions and Institutes, the PA framework is being increasingly used to filter out the less promising projects from a diverse range of research proposals.

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[28]The CSIRO definition of manufacturing is narrower than the definition employed by the Australian Bureau of Statistics (ABS). For example, it excludes the simple processing of primary products. It comprises ABS Socio-Economic Objectives codes 507, 509, 510, 511, 514, 515 and 599.

[29]Moreover there appears no reason to suspect a systematic bias in outcomes relative to CBA, although this observation warrants empirical verification.

The information needed to assess R&D proposals, whether at an early or late stage of development, typically resides in different organisations or, within organisations, in different departments. *Cost information*[30] involves expertise in R&D supply, and is typically the province of R&D managers, who have specific technical expertise in both in the expected resource needs of various technological goals and the degree of uncertainty and risk associated with them. *Revenue information*[31] is associated with the demand for R&D outcomes, and is typically the province of specialists in the relevant markets. For example, in the case of commercially-oriented product R&D, the demand-side expertise might be the province of the marketing manager, who could best determine the likely impact on price, market size and share, (and ultimately sales revenue and profits) of particular technological advantages over competitors.

To assess the returns likely from specific R&D investments, demand-side expertise must be combined with the supply-side expertise in order to cover both the prospective benefits and costs of proposed technological advances. ***In CBA,*** responsibility for distiling and combining the technical and marketing information to yield an expected monetary return, falls to the CB practitioner whose responsibilities also include distinguishing and valuing public benefits, providing formal distributions of likely benefits and costs under alternative scenarios, indicating the degree of uncertainty in the estimates, advising as appropriate on the distribution of benefits and costs over those effected by the R&D, and combining this information in the form of a comprehensive report. ***In the CSIRO priorities assessment*** the necessary expertise and information would ideally be assembled in one place and time, and directly used to reach a consensus decision[32].

Viewed from this perspective, the differences between the CSIRO priorities assessment and CBA depend mainly on their practice: the approaches have the same theoretical underpinnings . The choice between them might depend on the availability and location of the required information, the cost of assembling the experts relative to the costs of hiring a CB practitioner to seek and distribute information, corporate gains from using group decision processes, and the degree of rigour needed for management decisions. Taking such considerations into account, one might prefer the CSIRO PA framework to filter early R&D proposals

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[30]Cost information covers the relationship between desirable technological outcomes, and the resources needed to achieve them within the desired timeframe.

[31]Revenue information concerns the relationship between the value of the innovation as determined by its increment to unit value (price or benefit) and quantity used (sales volume). For public-sector R&D, non-commercial public needs and benefits would be considered along with the private commercial demands.

[32]The assessment by McKinsey & Company of CSIRO proposals for R&D aimed at developing rare earth processing facilities and down-stream rare earth magnet production in Australia used the feasibility and attractiveness concepts but the conduct of their research and the presentation of their findings was more representative of CB practice. It thus combined element of both frameworks.

and CBA for the detailed assessment of well-developed formal investment proposals.

The CSIRO framework for combining technological and marketing information closely parallels a framework advocated by the (US-based) Industrial Research Institute (IRI) as a means for improving the productivity of commercial research. The IRI and CSIRO frameworks use almost identical factors, described above for the CSIRO framework[33]. However, because the IRI framework actually quantifies technological progress in the form of physical units, the number generated by multiplying the commercial factor (attractiveness) by the technical factor (feasibility) does have meaning as a benefit-cost equivalent, viz the present value ratio of revenue flows to expenditure outlays. However this is possible only when the analysis is applied to the examination of research proposals *in a single product line or technological field*.

The application of the IRI framework to proposed innovation in a single product line is described below. The purpose is to demonstrate the equivalence of this type of framework to the cost-benefit framework, and reveal it to be a variant of CBA. The limitation to a single technology is not as significant a handicap as might be first considered. Research indicates technological growth can be characterised as incremental movements along technological trajectories. Such movements can be described in terms of parameters characteristic to the technology. (For example progress in information technology could be characterised by MIPS[34], progress in new transport materials as weight saved per product, etc.) This modern concept of relatively fixed technology trajectories differs from the traditional economic view of a virtually continuous technological frontier (Dosi, 1988).

A quantitative application of the IRI parallel might first use the research manager's expertise to relate the extent of technological progress along the technological trajectory – for an Information Technology company this might possibly be the increase in MIPS – to the level of R&D investment expenditure. One might expect that technological progress *per dollar of investment* would first increase, peak and then decrease with increases in the desired level or rate of progress[35].

Secondly the commercial return (in terms of prospective sales, prices and profits) to be expected from a product incorporating the advanced technological features might be provided by the marketing manager. The S-curve might also characterise the relationship between cumulative sales and degree of technical advance in the

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[33]Differences in the factors mainly reflect the different orientation of the two frameworks. Information on how the information described in Figures 4.3 and 4.4 might be adapted to rank R&D investment proposals is contained in IRI (1986) and McKinsey & Co (1987). The latter study expanded somewhat on the IRI's technical factor.

[34]Millions of instructions per second.

[35]This is characteristic of the "S-curve" for technological progress as described in Section 4.3

product, so that the dollar return per increment of technological advance might peak at some optimum level of technology. This latter marketing relationship is likely to be more uncertain than the former technological relationship.

The product of these two factors gives an investment assessment criterion, equivalent to the benefit-cost ratio[36]. which can be use to determine the optimum level of R&D investment. Applied in this way, the IRI framework is clearly a variant of cost-benefit analysis, one tailored to the special needs of research-intensive corporations. As such it is one of several variants of CBA tailored for specific applications (Appendix 4.1).

The IRI suggested the framework be used in a qualitative way to improve research productivity. In comparing R&D across product lines, managers may implicitly use rough dollar values for comparison purposes but would also incorporate other non-quantifiable factors in the decision process. Such an approach is essentially a form of decision analysis[37], another variant of cost-benefit analysis (Appendix 4.1).

As discussed above, the conclusions on the IRI commercial framework are also applicable to the CSIRO framework for public R&D. Although adapted to to cover broader issues than possible with the IRI approach described above, the CSIRO framework might also be viewed as a form of decision analysis. Moreover the CSIRO and IRI frameworks could yield similar results to CBA in ranking projects. Any systematic difference between these consistent decision-making frameworks could, if appropriate, be identified and corrected for.

Irrespective of which framework (CBA or the CSIRO method) were chosen to rank R&D proposals, the determination of the productivity benefits to Australian industry from the R&D would be an important consideration[38]. The methods described in Chapter 3 could assist because of similarities between underlying factors such as international competitiveness (Section 3.3.1) and import/export (See Figure 4.4 for factors determining attractiveness).

Both frameworks, in their application to prospective R&D, need detailed and reliable data. Ultimately good decision making requires not only good judgements, but also the data to support the judgements. Given the cost and uncertainty

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36Possibly discounted to present value terms with DCF techniques.

37In decision analysis (DA), the economic factors of CBA are only one input into the decision-making process. DA is recommended when a range of technical and market judgements have to be balanced against various constraints on resources. In such cases, traditional cost-benefit ratios, if they could be calculated, might not be sufficiently sensitive to distinguish between competing alternatives. For example CSIRO might have to decide whether to allocate additional resources to environmental research, or research into manufacturing technology, areas where the extent of intangible spillover benefits are so large as to remove quantitative precision and the associated objectivity.

38Although only as long as an equivalent product or process was available to these users at a similar or lower social cost from another source surrounding outcomes of R&D proposals, the CSIRO process could usefully serve as a hurdle to rule out R&D projects that appear least promising.

4.5 Application to the case-study projects

To more fully draw the implications of applying the CSIRO framework at the micro level of project selection, BIE staff have attempted to apply the CSIRO approach to the assessment of the case-study projects, and where possible, compare the results to what might have been expected from a prospective cost-benefit analysis made just prior to the commencement of the research. This exercise, which is hypothetical and mainly of heuristic value, is described in Annex A4.2.

The evaluation procedure focuses on the expected movement along the relevant technological trajectory. It is the innovation system rather than the underlying CSIRO R&D that is evaluated. This total or system approach is directly comparable to the total form of cost-benefit analysis, advocated in Section 3.1, which relates the benefits of innovation, both private and public, to the total public and private resources used to generate it.

This approach to project selection has the immediate effect of involving CSIRO's industrial collaborator either implicitly or explicitly in the project definition and decision making. In particular the collaborator might have better market information, while CSIRO might have greater insight into industry's future needs and most promising technological fields (ie CSIRO expertise is grounded in "feasibility", while expertise in the "attractiveness" is concentrated in CSIRO's commercial partner). The absence of a commercial partner, either present or potential, invalidates the evaluation[39]. This precondition is completely consistent with CSIRO rules which in determining the "capture" of the "potential" benefits examines whether users can exploit either the full potential or at least retain a substantial portion (Figure 4.3). It is also consistent with CBA.

The system approach used in Annex A4.2 to look at the case-study projects from a perspective of the CSIRO priorities assessment framework allows the collaborator to influence the technical aspects of the innovation and CSIRO to influence the economic take-up factors. This adds complexity to the analysis but in return generates useful insights into the innovation system. Nevertheless a simpler and equally valid approach would be to identify the technical aspects (feasibility) with the CSIRO input and the market aspects (attractiveness) with the collaborator. This latter approach, not adopted here, would be more typical of the way the priority assessment framework has been used in CSIRO.

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[39] It is not possible to completely rule out the separate sale of the R&D particularly if property rights can be tightly controlled, but past experience counsels considerable caution.

4.6 Conclusions

CBA and the CSIRO priorities assessment framework have the potential to complement each other, first in setting broad strategic directions for R&D and secondly in ranking and evaluating specific R&D projects. To draw out its relationship with CBA, the CSIRO framework was applied to the case-study projects. Some findings were:

Importance of data:
The selection process based on the CSIRO PA method, like prospective cost-benefit analysis, is only as useful as the data on which it is based. The analysis described in Annex A4.2 lacked data on world market, cost, profits for the given projects. The consequent ranking of projects is mainly conjectural.

Assessing the criteria:
As indicated in Chapter 3, the quantification of many benefits is extremely difficult. However it was concluded that in many cases the benefits were second order in magnitude and as such should not play a significant part in decision making. It is unclear what value would be derived from the corresponding criteria in the CSIRO PA framework, but it is possible that it could be given a significant weight, and hence differ from CBA.

Combining qualitative criteria:
The CSIRO PA method, unlike prospective cost-benefit analysis, does not provide specific guidance as to how the different criteria are to be combined. As shown in Chapter 3, qualitative criteria, although valid in their own right, if added together to get an overall project score, might be a poor basis for project selection because of double counting.

The conclusion from these findings is that despite the data problems, the application of the CSIRO framework could give results consistent with prospective CBA. Interestingly, in its application to the case-study projects, the method as applied by the BIE found all projects would have been likely to have been selected. This is reassuring given the retrospective cost-benefit analysis showed them to be in the national interest.

5. Conclusions

5.1 Overview

This chapter considers the implications of the case-study evaluations for CSIRO-generated innovations in industrial and communication technologies. The fundamental issue is whether the innovation processes are efficacious: this can be conveniently broken into examinations of the performance and the choice of R&D projects, and the policy environment in which they are conducted.

The implications for research performance are made on the basis of the innovative activities covered by the four case studies outlined in Chapter 2. The implications for project selection stem from the discussions firstly of economic criteria in Chapter 3 and secondly of the CSIRO priority assessment framework in Chapter 4.

Various government policies influence the efficiency of CSIRO-generated innovation in Australia. Such policies include those directed at CSIRO (eg funding), those directed at industry (eg public support of private sector R&D) and those concerned with the interaction between research establishments and industry. The effect of such policies was observed in the case-study projects[40]. However the focus of the case studies was not directed towards an examination of the effectiveness of such policies, and the indirect effects observed during the project do not provide a sufficiently broad basis for comment on their efficacy.

5.2 Implications for research performance

The efficiency of the innovation process was an issue in the assessment of the selected CSIRO projects. The focus was on the overall innovation process rather than "within CSIRO" R&D, and on the economic rather than the scientific performance of the R&D. Overall efficiency in the innovation process requires not only efficiency in its components (eg research, development and commercialisation[41]) but also appropriate balance between them.

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[40] An example was an initial customer resistance to increased CSIRO charges following implementation of CSIRO's external funding objectives was observed in the standards and earth station antenna projects.

[41] This optimal mix of activities in innovation is frequently considered to require, in absolute terms, $100 on commercialisation and $10 on development for every one dollar of research.

Appropriate balance, in theoretical terms, occurs when the benefit to Australia from the expenditure of an additional dollar on innovation does not depend on where in the innovation chain the additional dollar is spent[42,43].

Where marginal expenditure on innovation is determined jointly by Government – on the basis of the foreseen future needs of industry, and by industry – on the basis of its foreseeable needs, close interaction is necessary if the appropriate balance of activities is to be attained.

Interaction between CSIRO and industry

While the interdependence of science and commerce has long been recognised, their efficient combination has often presented organisational difficulties[44]. The organisational problems are likely to be greatest when the research is conducted in government laboratories which are separated, physically, organisationally and culturally, from the commercialisation process[45]. Inadequate interaction between researchers, developers and the users of the innovation means that benefits associated with feedback and cross flows of information are not captured.

The case studies suggest that the need for feedback and cross-exchange of information has been recognised and that by and large the degree of interaction is adequate. For example, the Dunlena agreement, made early in the research program, provided for extensive feedback and interaction between CSIRO and Du Pont[46], and has an inbuilt flexibility facilitating its adaption to changed circumstances. It can be regarded as a model for interaction. In the CDT project, a two-way learning process[47] was critical in converting a process established in laboratory conditions into a commercially successful product. In the ES antenna project, commercialising the technological capabilities and skills that had been built up from pioneering research in radioastronomy involved close liaison with

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42 This is a necessary condition for system optimality. In some circumstances, the theoretical ideal might not be obtained, in the presence of economies of scale, lumpiness in some activities, complementarity between activities etc.

43 Private organisations would be expected to allocate the funding available to them in a way that maximises their private returns. If the R&D component is relatively cheaper, by virtue of Government subsidy (through tax incentives or subsidies to Government laboratories) then their marginal expenditure will be more heavily weighted towards the research component of innovation, a pre-competitive domain where the greatest spillover effects are alleged to be concentrated.

44 The BIE has looked at the comparative advantages of three ways in which resources can be allocated, markets, firms, and networks, and impediments to their efficient function in Discussion Paper 14 "Networks a Third Form of Organisation". It found networks offered advantages in the domain of S&T.

45 The linkages need not only strength, but also the flexibility to adapt quickly to changing circumstance.

46 Another factor was gaining access to Du Pont's extensive field testing program.

47 CSIRO scientists learning from WIA's production and marketing engineers and vice versa.

OTC, the main Australian purchaser, and the Australian manufacturers of sophisticated components[48].

Balance between research activities and commercialisation

Commercial and social returns are generally realised after commercialisation when research findings are implemented in innovative activity. Commercialisation takes place outside CSIRO – typically the rights to CSIRO research will be purchased by a business enterprise which may have collaborated with CSIRO in the project. The question arises as to whether the investment by the industrial collaborator in commercialisation will necessarily maximise the expected total of private and public returns.

A major reason why the maximum return might not be generated from a CSIRO R&D breakthrough is that the industrial collaborator might not have the resources needed to attain as high a return on the R&D component of its total investment as that available to a competitor. Both the collaborator and a competitor would maximise the private returns on their total investment. However, the necessary investment in assets that complement the R&D (international marketing networks, reputation, etc) might be more costly to the CSIRO collaborator than the competitor because of barriers to entry, economies of scale, etc.

On the basis of the case studies it appears that the choice of collaborator can limit the total returns from CSIRO research. For example, the relative smallness of WIA in the Australian market, its limited financial strength, and its lack of experience in international marketing reduced the returns potentially available to CSIRO's CDT research[49]. On the other hand, the more recent Dunlena experience demonstrates a successful use of market-based mechanisms to select an industrial collaborator. For the ES antenna project, there was only one feasible industrial collaborator, viz OTC[50].

Balance between strategic research and product development

In all four case studies, the commercial applications were built upon already established technological capability and scientific expertise. This base capability derived from the conduct of basic research and from keeping abreast of overseas developments.

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[48]The CSIRO design skills complemented OTC's skills in producing satellite earth stations and were most effectively used early in the design process.

[49]In today's industrial research environment, collaboration with an international company would not experience the same impediments as faced by the CDT developers in 1980.

[50]Overseas manufacturers of earth stations either had their own in-house capability or preferred to support national capability, possibly because of spin-off benefits in gaining defence contracts.

Balance between different research activities can be an outcome if the R&D is effectively directed and the evidence of the case studies suggests this direction was present in two of the four case studies. The direction of crop-protection chemical research was influenced by market pull through Du Pont's influence. Australian research in measurement science was influenced through its participation in international research programs.

However in the other two case studies, the underlying strategic research was not directed by potential commercial needs. The fundamental research in plasma arcs, which underlay the CDT development, was initially driven by the pursuit of academic excellence and leadership in an area of industrial potential, and later by the perceived needs of manufacturing growth in Australia. However the idea for the pulse generator, the device on which the CDT is based, arose as a means to solve an industrial welding problem. Australia's position as a leader in antenna design was built on a foundation of astronomical research in the 1960s. These two case studies point to the role of serendipity in public-sector led innovation, and the difficulty in foreseeing future commercial applications of research.

5.3 Implications for project selection

A number of economic criteria that could influence choice of project were presented in Chapters 3 and 4. These form part of the complete set of decision variables a decision maker in CSIRO might consider in making R&D investment decisions. These, when used in an appropriate decision-making framework, should ensure R&D investment decisions are optimised.

The most general decision-making framework is decision analysis[51]. Decision analysis can incorporated both the CB framework[52] (Chapter 3) and the CSIRO PA framework[53] (Chapter 4). These alternative two frameworks were shown to complement each other in project selection.

The CB framework was found to have the advantage of being able to incorporate various economic criteria. However for prospective evaluations it was subject to

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[51] Efficient decision making has certain characteristics whether the criteria used are scientific, economic or both. Decision making has been extensively studied, eg in academic institutions, and its properties identified. Systematic approaches to decision making are to be preferred over ad hoc ones, conferring consistency in the on-going decision-making process, and enabling the process itself to be evaluated and improved.

[52] Cost-benefit analysis, the first of the evaluation criteria, is one of five variants of decision analysis discussed in Appendix A4.1.

[53] The CSIRO PA framework is associated with its annual budget process. The aim of the process is essentially economic, ie to allocate resources among the diverse areas of research in a way that maximises the benefit to Australia. In common with the the other decision rules discussed in Annex A4.1, it offers a consistent and systematic approach to decision making. However its design has been specifically tailored to CSIRO needs.

practical implementation difficulties: the case studies demonstrate that a considerable depth of specialist knowledge, not always readily available to a consultant, would be needed to make accurate assessments of uncertain future options[54].

The economic rules implicit in the CB framework confer two types of benefit on decision making. The first is that the aggregate benefit from interrelated impacts[55] is determined in a consistent and sound way. The second is that the decision rules for choosing the combination of projects that contribute most to economic wellbeing[56] are explicitly defined. The former benefit may be most applicable to CSIRO decision makers. It makes explicit how to compare projects with different characteristics eg risk.

The CSIRO PA framework has two main roles: direction-setting for the organisation and the screening of preliminary R&D proposals within CSIRO Divisions and Institutes. It is in the latter role that the case-study examples might prove most useful. In particular, they may assist in assessing the aggregate benefit from export potential, commercialisation prospects, inter-industry effects etc for R&D projects, particularly projects offering different opportunities to Australian manufacturers and whose potential benefits have different time and risk profiles.

5.4 Conclusion

Interaction and balance between research and commercialisation are essential ingredients for efficiency in innovation. The case studies found the degree of *interaction* was appropriate. The need for interaction was greatest for research in crop-protection chemicals, and it is in this area that the Dunlena agreement between CSIRO and Du Pont serves as a model. The *balance* between research and commercialisation varied over the case studies, with the CDT project, albeit dated and not representative of today's environment, indicating insufficient effort to commercialisation.

Problems of interaction and balance can be averted by appropriate choice of project – projects in fields where industrial companies with appropriate manufacturing and marketing skills seek CSIRO collaboration in innovation are least likely to face problems in commercialisation.

[54]In the same way, economic audits are not a substitute for scientific audits, through for example, peer review.

[55]Eg methods for aggregating revenue flows at different points in time, procedures for estimating intangible benefits such as human life, when market prices are not a good guide to economic benefits, treatment of risk and uncertainty, etc. For information on these aspects, see Department of Finance (1990).

[56]Eg select projects with highest net present value and benefit-cost ratios.

The CB and CSIRO PA frameworks complement each other in ensuring that the most appropriate R&D projects are selected. In both frameworks determining the relative importance of various contributing factors is important. The case-study evaluations can contribute to the economic assessment of factors such as export potential, human capital development and demonstration effects. Appropriate consideration of such economic factors, alongside the technical factors which are the chief province of CSIRO scientists, should assist future project selection by CSIRO's industrial researchers.

ANNEX A4.1

ALTERNATIVE DECISION MAKING METHODS

The following variants of cost-benefit analysis are described more fully in OECD (1989).

Cost-effectiveness analysis (CEA)

The corporate objectives of CSIRO's manufacturing research are to enhance the efficiency, international competitiveness and growth of Australian industries. Under CEA, these would be taken as the objectives[57] to be achieved. The benefits of this objective would not be valued. Instead alternative ways of attaining these objectives would be explored. The best way would be the least cost one, providing the distribution of the costs is not a consideration[58] .

This approach solves the problems of valuing intangibles and combining non-pecuniary benefits. However there remains the problem of a constructing a counterfactual, an alternative with the same effects as a given CSIRO innovation. If the innovation is not used as a competitive tool, then this is not a problem - the cost of purchasing the innovation from another source, perhaps overseas, is the counterfactual situation used for comparison.

For example, CEA is recommended for determining resource allocation within the National Standards Laboratory. An alternative to CSIRO as a source of a particular standards might be an overseas laboratory. The cost advantage of using CSIRO rather than overseas laboratories is a measure of the maximum benefit of CSIRO's facilities in that particular measurement field[59].

Risk-benefit analysis (RBA)

This cost-benefit variant compares the risk of undesirable effects associated with no CSIRO research to the costs of undertaking the research. It essentially compares the probability of such risks to the cost of averting them. It has little to offer in this project.

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[57] After quantification.

[58] The "dollar is a dollar rule" of CB analysis.

[59] The benefit of the standards facility might be less than the excess costs associated with overseas sourcing of primary standards.

Multi-criteria analysis (MCA)

Because the desirable outcomes of CSIRO's research (Table 1.1) cannot be easily expressed in money values, they cannot be combined with the more conventional items of CBA to give one overall indicator. MCA overcomes this problem by imputing dollar values to each of the outcomes in line with their perceived importance. The difficulty with this variant is the arbitrariness and subjectivity in assigning weights to different outcomes. The advantage is that if the monetary values to be assigned to different outcomes can be agreed, their application will give a indicator that is consistent across projects.

Decision Analysis (DA)

This is a cost-benefit framework designed to allow decision makers to take explicit account of the probability of uncertain outcomes. It is a framework that could be used by research managers in allocating resources across projects. In such an event, it would include more factors than those to be used for our evaluation[60].

DA could be used in-house by CSIRO to complement their own management methods.

[60] For example it would take account of constraints on the available resources, and hunches as to the future direction of technology and markets.

ANNEX A4.2

FEASIBILITY & ATTRACTIVENESS IN THE CASE STUDIES

The assumptions underlying the application of the CSIRO priorities assessment framework to the four case studies are outlined in Section 4.5. That section also distinguishes the *systems* approach, used below, in which both CSIRO and their industrial collaborator can separately influence both the attractiveness and feasibility of innovation, from a less complex approach, as might be used within CSIRO, in which full responsibility for the innovation's feasibility is accorded to CSIRO.

The feasibility of the case-study projects

The technical trajectory associated with *welding equipment* could be characterised by productivity improvements, through higher weld quality (less reworking), wider application (stainless steels, aluminium), and greater simplicity in control. The planned development of the CDT pulse welder would advance it to the frontier of world leadership in these technical features. Such a leap forward along the technological trajectory indicates a relatively high R&D potential.

The capacity to develop this welder's technical performance to its full potential would depend, not only on CSIRO, but also the collaborator, WIA. CSIRO's capability and expertise in the provision of the necessary scientific expertise would not be questioned, and this judgement was in fact born out over the project. WIA's ability and commitment to provide the engineering and production expertise necessary to guarantee the product's technological leadership would be less certain. In the event, WIA's provision of this technical expertise proved more than adequate to satisfy the local market's minimum expectations. However the evidence suggests that WIA was not committed to seeking world quality or to ensuring the necessary technical upgrade to maintain its technological edge over competitors.

The capacity to achieve the product's potential, relative to that of its international competitors, was somewhat weakened by the technical commitment of the Australian collaborator. On the feasibility screen (Figure A4.1), this effect is illustrated by an arrow showing the projected effect of the collaborator on the capacity of the CSIRO-WIA team to achieve the full technical potential.

With *crop-protection chemicals*, the technological trajectory could be measured in terms of specificity of the control agent to a particular pest, the in-the-field control possible in low concentrations and with infrequent applications, and the cost of manufacture and use. Although the search for new crop-protection chemicals with such characteristics is scientifically based, there is a level of uncertainty as to whether the new chemicals emerging from the innovation pipeline will incorporate the desired characteristics. A high serendipity factor is acknowledged. Because of this risk factor, the assessment of R&D potential is represented on the feasibility screen being more mid-range than high.

In view of CSIRO's reputation for scientific expertise and capability in this field[61], their capacity to achieve significant advances in these technical characteristics would be judged fairly high, despite shortcomings in the capability for field-testing, etc. A relationship with Du Pont, whose technical capabilities complement CSIRO's would certainly enhance capacity, in effect steepening the "S-curve" ie permitting the technological progress to be achieved with less effort. Relative to other international researchers in this field, the CSIRO - Du Pont partnership does not appear to be significantly disadvantaged. The feasibility screen (Figure A4.1) demonstrates by arrow how the project's R&D potential and its capacity to achieve this potential is enhanced by Du Pont's technical skills.

The *earth station antenna* technological trajectory was known to be limited, even at the time of the first satellites, by the advent of optical fibre technology. For this reason the scope for a large advance in this technology was remote. A high position on the S-curve suggests relatively low R&D potential and calls for incremental rather than breakthrough research. The capacity of CSIRO to effectively realise these incremental gains is very high. The relationship with OTC is judged to neither retard nor advance the potential or capacity of this R&D (Figure A4.1).

Movement along the *measurement* technology trajectory is measured by the increase in accuracy and reliability of standards and calibration. In specific measurement fields, eg time interval, there is still the potential for large jumps forward, although, by and large, measurement science might be regarded as towards the top of its S-curve. For this reason, it rates a relatively low rating on the potential scale. In terms of capacity, this research area is atypical of CSIRO, in that the research effort to improve world standards is cooperative rather than competitive, so that while Australia may not have the resources to make the same breakthroughs as the leading national measurement laboratories, it has access to the findings by virtue of its contribution. Moreover it has the expertise needed to assimilate any overseas research findings. This all points to a high rating on the capacity axis[62].

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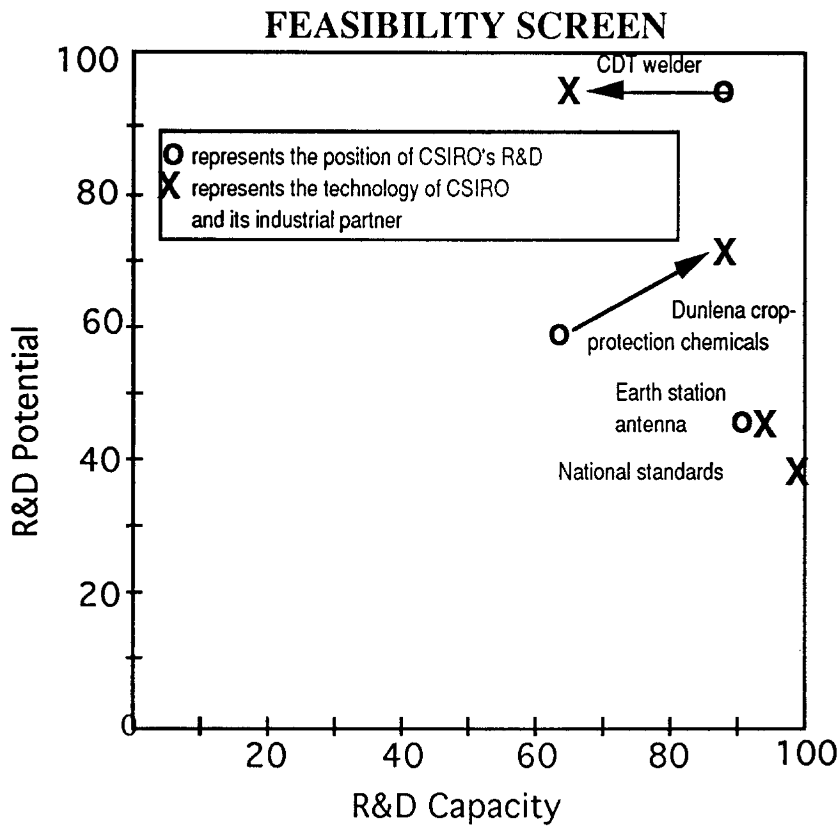
[61] Demonstrated by their discovery of cycloprothrin and their portfolio of patents.

[62] It does not have an industrial partner as such, so no arrow is shown on the feasibility screen.

Figure A4.1 Feasibility of case-study projects



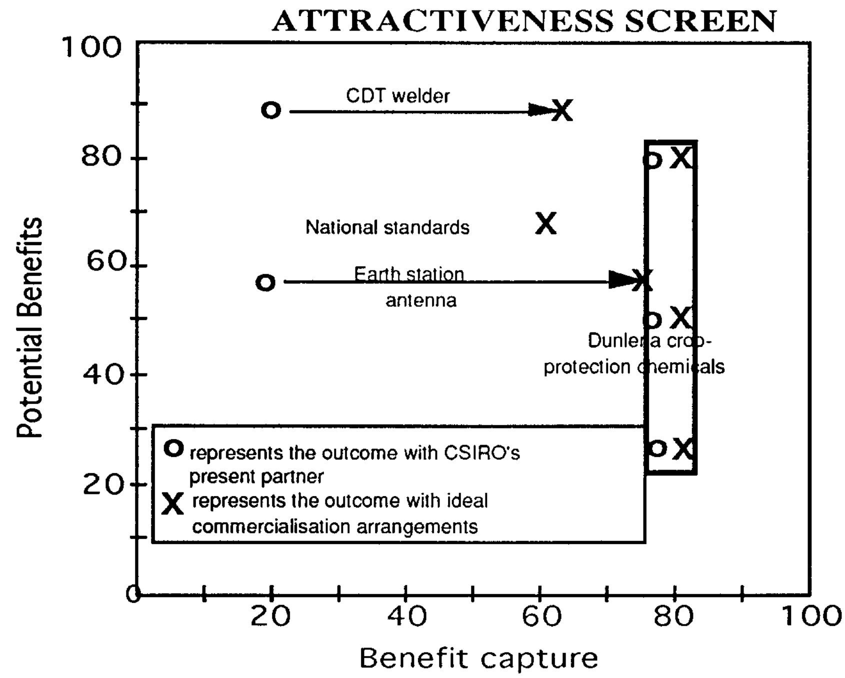
Note: As a qualitative exercise, the scales shown on the axis have no cardinal properties.

The attractiveness of the case-study projects.

A technological advance to the frontier of world progress would be expected to generate large increases in market size and share. The world market become potentially available, and the commercial returns are commensurably high. However market characteristics, for example those associated with differentiated products, could be regarded as limiting the commercial potential. On balance because of the significant first-mover advantages inherent in the CDT's design, this project was rated high in potential benefits (Figure A4.2).

The capacity to achieve the potential benefits associated with gaining a significant share in world markets would be limited by foreseeable difficulty in arranging access to national markets, each of which had its own well-established domestic manufacturers. High market penetration of its particular segment of the Australian market for new welders would be almost ensured given WIA well-established market profile and CSIRO's backing and support. However achieving the international collaboration would have been expected to present difficulties. This probable limit to realising full commercial benefits available from exports sales has an offset. Restriction to the welding knowhow implicit in the CDT usage would assist the competitiveness of Australian manufacturers using it.

Figure A4.2 Attractiveness of case-study projects



Note: As a qualitative exercise, the scales shown on the axis have no cardinal properties.

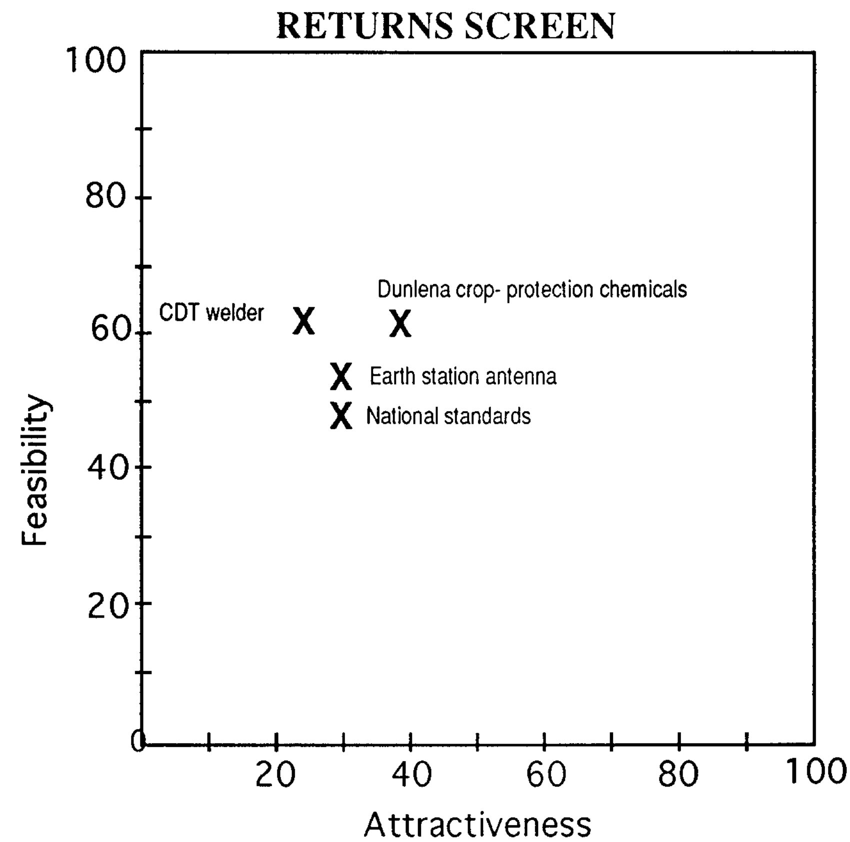
The potential benefits to be expected from the *Dunlena* project , if crop-protection chemicals are successfully developed, depends critically on the particular advantages of the chemicals produced. As shown on attractiveness chart, while Australia's ability to capture to benefits is uniformly high due to the arrangement with Du Pont, the extent of the benefits is subject to unusually high uncertainty.

The potential benefits in a more technologically mature technology such as earth station antennas would be less subject to uncertainty, but would be limited by the incremental nature of the research. The need to use OTC as a partner could arguably limit its market spread compared to the ideal situation of a free market in antenna design services. The presence of in-house skills by overseas suppliers of turn-key plants would severely limit the ability to capture the commercial benefits associated with large exports markets, but it would be expected to contribute to the Australian industry's competitiveness.

The return to Australia from the case-study projects.

The feasibility and attractiveness factors are combined on the "returns" screen (Figure A4.3). Despite their various properties, this screen suggests the projects would all be clustered towards the centre of the graph.

Figure A4.3 Returns screen for case-study projects



Note: As a qualitative exercise, the scales shown on the axis have no cardinal properties.

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